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Exposure to volatile organic compounds in healthcare settings

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Abstract

Objectives—To identify and summarise volatile organic compound (VOC) exposure profiles of healthcare occupations.

Methods—Personal (n=143) and mobile area (n=207) evacuated canisters were collected and analysed by a gas chromatograph/mass spectrometer to assess exposures to 14 VOCs among 14 healthcare occupations in five hospitals. Participants were volunteers identified by their supervisors. Summary statistics were calculated by occupation. Principal component analysis (PCA) was used to reduce the 14 analyte inputs to five orthogonal factors and identify occupations that were associated with these factors. Linear regressions were used to assess the association between personal and mobile area samples.

Results—Exposure profiles differed among occupations; ethanol had the highest geometric mean (GM) among nursing assistants (~4900 and ~1900 μg/m^3, personal and area), and 2-propanol had the highest GM among medical equipment preparers (~4600 and ~2000 μg/m^3, personal and area). The highest total personal VOC exposures were among nursing assistants (~9200 μg/m^3), licensed practical nurses (~8700 μg/m^3) and medical equipment preparers (~7900 μg/m^3). The influence of the PCA factors developed from personal exposure estimates varied by occupation, which enabled a comparative assessment of occupations. For example, factor 1, indicative of solvent use, was positively correlated with clinical laboratory and floor stripping/waxing occupations and tasks. Overall, a significant correlation was observed (r=0.88) between matched personal and mobile area samples, but varied considerably by analyte (r=0.23–0.64).

Conclusions—Healthcare workers are exposed to a variety of chemicals that vary with the activities and products used during activities. These VOC profiles are useful for estimating exposures for occupational hazard ranking for industrial hygienists as well as epidemiological studies.

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INTRODUCTION

Healthcare is the largest industry in the USA.[1] Healthcare workers have an elevated risk for workrelated asthma (WRA), which includes occupational asthma and work-exacerbated asthma.[2-7] According to the National Institute for Occupational Safety and Health (NIOSH)-sponsored Sentinel Event Notification Systems for Occupational Risks (SENSOR), US healthcare workers were disproportionately represented among WRA cases, with 16% of the cases but only 8% of the workforce, in the four states where surveillance was conducted.[4] Using the National Health Interview Survey data from 1997 to 2004 for 42 different occupations, lifetime prevalence of asthma was highest for the occupational categories of 'health services' and 'health technologist and technician', both at 11.5%.[8] Several specific healthcare occupations have been associated with risk of WRA including nurses, nursing aides/technicians, respiratory therapists (RT), radiology technicians, laboratory workers and cleaners/housekeepers (HK).[3-5910]

Studies have reported an association between WRA and exposure to groups of agents, such as cleaning and disinfecting products, latex, indoor air pollution, volatile organic compounds (VOCs), bioaerosols, ammonia-containing or chlorinecontaining products, chemicals used for cleaning instruments or building surfaces and use of aerosolised medicine, in a range of healthcare occupations. [391112] Cleaning and disinfecting products constitute a complex mixture of chemicals that include irritants (eg, bleach and ammonia) and sensitisers (eg, quaternary ammonium compounds and ethanolamines) that have been characterised as asthmagens by several organisations, including the Association of Occupational and Environmental Clinics.[13-15] Exposures associated with irritant-induced asthma are not as well understood or characterised as are exposures associated with sensitiser-induced asthma.[1314] Exposures to VOCs have been used as a surrogate for cleaning and disinfecting products,[16] and some VOCs are associated with irritant-induced asthma.[17-21]

Population-based epidemiological studies of asthma or respiratory symptoms among healthcare workers have used a range of qualitative or semiquantitative exposure metrics, including general or asthma-specific job exposure matrices with or without expert judgement,[102223] tasks performed, products used,[324] exposure factors[25] or self-reported exposures,[4] and their duration and frequency[9] as proxies for exposure. These studies have most likely suffered, to some degree, from nondifferential or differential exposure misclassification.[2627] Several studies have called for quantitative exposure data in studies of occupational asthma to identify specific agents, minimise exposure misclassification and obtain quantitative exposure–response relationships that support the development of exposure limits and prevention strategies to minimise sensitisation and respiratory outcomes.[2829]

The current study is part of a larger ongoing epidemiological study to investigate relationships between exposures to asthmagenic cleaning and disinfecting products among healthcare workers and risk of WRA or asthma-like symptoms. As in a previous study,[16] VOC exposures were used as a surrogate for cleaning and disinfecting products, though it is recognised that in real-world environments, measured VOC concentrations may also include sources besides those from cleaning and disinfecting tasks or products. Healthcare settings

present a challenging environment for assessing low-level concentrations of VOCs due to high background concentrations of alcohols from the use of alcohol-based hand sanitisers and surface cleaners. Thus, in this research, we sought to accurately characterise exposures consisting of low μg/m^3 level VOC concentrations in the presence of a mg/m^3 level VOC background (ie, alcohol) among 14 occupations in healthcare settings.

METHODS

Site information

A preliminary sampling campaign was conducted at a US Veterans Affairs (VA) hospital for five consecutive days in April of 2009 to develop appropriate sampling protocols and refine the sampling and analysis methods (see online supplementary appendix). Utilising the knowledge acquired from the pilot study, exposure assessment studies were conducted at three different VA hospitals and two teaching hospitals during the spring and summer of 2009–2011. Supervisors identified participants from 14 targeted occupations. Research staff obtained verbal consent from each worker to participate in exposure monitoring (table 1). Sampling information is summarised in table 1, indicating the number of healthcare facilities from which occupations were monitored, the total number of air samples collected and the number of workers monitored for each occupation.

Sampling

The sampling strategy was to perform full-shift monitoring for three to four workers from each of the 14 occupations within each facility on at least two occasions; however, this approach was not always feasible for all combinations of occupation and facility because of the lack of workers on shift, lack of volunteers to participate and/or limited staff members from whom to select (table 1). Full-shift measurements were mostly collected during the day and began at the start of the morning shift; floor strippers/waxers (FSW) were sampled at night during their regular work schedule. The volunteers were asked to perform their usual duties in an effort to characterise their typical VOC profile without modification to the tasks or products used. No demographic information was collected on participants. The sampling set-up included an array of real-time and timeintegrated personal and ‘mobile area’ sampling instruments. Conventional area sampling is stationary around a process or employee who is being monitored. The nature of the tasks for healthcare occupations required perambulatory movement, necessitating the design of mobile area monitoring. The mobile area basket was transported by the sampling technician who maintained a close proximity (within ~1.5 m) to the healthcare worker for most of the time except when hospital policy or patient care prevented them from doing so. Employees were instructed to leave personal samplers next to mobile area baskets if they were going out to smoke since tobacco smoke is a major source of benzene. Information on the distance of the area basket from the worker was noted in the work sampling sheets. The mobile area sampling instruments consisted of a basket with a Silonite-coated (Entech Instruments, Inc, Simi Valley, CA) evacuated 6 L canister equipped with a CS1200 flow controller (Entech Instruments, Inc) set to 10 mL/min, a realtime VOC monitor (ppbRAE Plus monitor, RAE Systems, San Jose, California, USA) to measure ppb-level total VOC (TVOC) concentrations and a real-time temperature and relative humidity monitor (model PRHTEMP 101, MadgeTech, West Warner, New

Hampshire, USA). The real-time TVOC monitors provide information on intermittent exposure events that are not resolved on time-integrated samples. Personal samples were collected from the workers' breathing zone using a Silonite-coated (Entech Instruments, Inc) evacuated 400 mL canister with an external capillary-based flow controller starting with the second hospital (the personal sampler was not available at the beginning of the study). A real-time ppm-level TVOC monitor (ToxiRae) was also worn by the employee. A field blank and outside sample was collected each day using a 6 L evacuated canister. Only the results of canister sampling are presented.

Analysis

A previously validated evacuated canister method (personal 400 mL and area 6 L) was used to quantify the following analytes that were prevalent in healthcare settings during preliminary sampling or may be associated with asthma: ethanol, acetone, 2-propanol, methylene chloride, hexane, chloroform, benzene, methyl methacrylate, toluene, ethylbenzene, m, p-xylene, o-xylene, α-pinene and d-limonene.[30] These chemicals may arise from use of cleaning and disinfecting products as well as from chemicals used in laboratories such as xylenes in histology or methyl methacrylate in dental. Analysis was conducted according to the method using a preconcentrator attached to a gas chromatograph/mass spectrometer system. A single metric of TVOC exposure (TVOCMIX) was calculated as the sum of the 14 analyte concentrations. This metric is most likely an underestimation of exposure because it represents only the subset of VOC constituents in the air that were quantified during analysis.

Statistical analysis

All statistical analyses were performed using SAS V.9.1 (SAS Institute, Inc, Cary, North Carolina, USA) and JMP V.9.0 (SAS Institute, Inc) with a 95% confidence level. Descriptive statistics, frequencies and probability plots were generated to summarise chemical profiles for occupations, pooled across facilities. Geometric means (GM) and geometric SDs (GSD) were calculated for occupations, and the maximum likelihood estimate method via the NLMIXED procedure in SAS was used to account for data below the limit of detection (LOD).[31] Principal component analysis (PCA) was performed using log-transformed measurements of the 14 analytes as input variables to identify groups of analytes that shared some common underlying characteristics (ie, latent factors), as an approach to variable reduction while maintaining a significant amount of explained variance in measurement data.[32] The underlying characteristics may be based on common jobs or tasks performed, chemical products used, location, ambient environment or other unknown characteristics. An added benefit of PCA was a reduction of collinearity among independent variables of exposures by providing orthogonal input for further modelling efforts such as for use in job-exposure matrices.[33] These orthogonal inputs are principal component scores, which are linear combinations of optimally weighted observed variables. The number of components retained in the model was determined using the Kaiser criterion and scree plots. The Kaiser criterion states that components whose eigenvalues are greater than one significantly contribute to the variance and should be retained. A scree plot is a graphical representation of the eigenvalues by number of components to identify natural breaks in the eigenvalues. The scores were then transformed using a varimax rotation to produce factor

loadings, which are bivariate correlations between observed variables and components. To evaluate the influence of occupation on the principal component factors, a bar graph of the mean factor loadings from the PCA was generated. Mahalanobis distance[34] was used to remove outliers (14/170) prior to graphing in order to aid in the visual interpretation of the distributions. Pearson correlation coefficients were calculated to evaluate the relationships between mobile area and personal measurements overall and by analytes. A mixed-effects model with worker as a random affect and the fixed effects of occupation and analyte was also fit using JMP to explore the association between mobile area and personal measurements.

RESULTS

Histograms and probability plots constructed for specific VOCs by occupation and sample type indicated that, while most measurements fit a lognormal distribution, some displayed bimodal or multimodal distributions (data not shown). All data were logtransformed prior to statistical analyses. For those chemicals present at the highest concentrations (TVOCMIX, ethanol and 2-propanol), GM exposures were plotted by occupation and sampler type (figure 1). Occupations were initially sorted by descending order of analyte concentrations for personal TVOCMIX exposures, and that order was maintained throughout the figures for consistency. Personal sample measurements were generally higher than mobile area measurements. The highest personal TVOCMIX exposures occurred among nursing assistants (NA), licensed practical nurses (LPN) and medical equipment preparers (MEP). The highest mobile area TVOCMIX exposures occurred among dental assistants (DA), LPN and pharmacists/pharmacy technicians (PT). Regardless of sample type, TVOCMIX concentrations were driven by just two compounds: ethanol and 2-propanol. Contrary to expectation, FSW and HK were not exposed to the higher levels of TVOCs or specific VOCs measured here. This may have been due to the following: low volatility of the chemicals in products used by these occupations; low frequency and/or short duration of use for the alcohol-containing products. The remaining 12 analytes of interest were present at relatively lower concentrations (low $\mu g/m^3$ concentrations).

GM exposure concentrations of acetone, toluene and limonene (as representative low-level VOC exposures) by occupation are displayed in figure 2. The highest personal exposures to acetone (figure 2A) were among clinical laboratory technicians (CLT) and LPN. The highest area exposures to acetone were among FSW and medical appliance technicians. For toluene (figure 2B), the highest personal exposures were among CLT and medical appliance technicians. Personal sampling results for toluene were approximately 16 times higher than area measurements. For limonene (figure 2C), the highest exposure occupation for both personal and area sampling was medical appliance technician. For the most part, personal measurements were higher than area measurements except for limonene. The discrepancy between personal and area measurement is most likely due to the location of sources relative to the receiver (ie, the mobile area or personal sampling locations).

GMs and GSDs for VOC measurements by occupation and sampler type are provided in online supplementary appendix table S1. For acetone, ethanol, 2-propanol, toluene and m, p-xylene, there were very few measurements below analytical LODs across all occupations for

personal and mobile area measurements; chloroform, hexane, benzene and limonene also had few measurements below LODs for mobile area samples across all occupations. Mobile area samples had smaller fractions of measurements less than the LOD overall, and for specific VOCs across all occupations. Personal measurements for methyl methacrylate were highest among DA and NA, and lower than or close to the LOD for the remaining occupations. CLT had the highest levels of acetone, and were among the higher exposed occupations for m,p-xylenes and toluene. Personal exposures to limonene were highest among medical appliance technicians and MEP.

In addition to the 14 target VOCs that were quantified, other VOCs were identified by comparison with a National Institute for Standards and Technology 2008 mass spectral library with a subjective quality factor of 75%. A total of 110 compounds were qualitatively identified in the mass spectra and grouped into classes (see online supplementary appendix table S2). These qualitatively identified compounds had varying exposure patterns by occupation (data not shown). For example, isoflurane, an anaesthetic, was identified in samples from surgical technologists, registered nurses (RN) and RT; sevoflurane (anaesthetic) in endoscopy technicians and RN; norflurane (anaesthetic) in CLT, LPN and DA; isoprene (plant and human emission) in HK, FSW, LPN and RN and 1,1-difluoroethane (refrigerant and propellant) in dental laboratory technicians (DLT), RT, LPN, DA, endoscopy technicians and HK. A formal investigation of the association of these chemicals to occupations is ongoing using multivariate methods.

PCA was used to analyse the log-transformed personal sample data for the 14 target VOC analytes as inputs; field blanks (n=40) and outside (n=1) samples were excluded from analysis (PCA results for the area sample data are displayed in the online supplementary appendix). Five principal components captured 74.8% of the variance. Principal components 1 through 5 explained 33.6%, 14%, 11.6%, 8.2% and 7.4%, respectively, of the variance.

The analyte influence on the five factors is displayed as factor loadings in figure 3A. Positive values indicate a positive influence on the factor while the converse is true for negative values. The following analyte influence is apparent from the factor loading distribution as indicated by open diamonds above the bars when the factor loading was greater than 0.4 or less than −0.4 (figure 3A): factor 1—ethylbenzene, m,p-xylene, o-xylene and toluene, which are aromatics and may be indicative of solvent use in clinical laboratory procedures or floor stripping tasks; factor 2—chloroform, ethylbenzene, methyl methacrylate and α-pinene, which is a mixture of chlorinated and aromatic solvents, a monomer of acrylic resin and a terpene; factor 3—benzene and ethanol, which is a mixture of an aromatic and an alcohol; factor 4—acetone, benzene, hexane and methylene chloride, which is a mixture of a ketone, an aromatic, an alkane and a chlorinated hydrocarbon and may be indicative of solvent use and factor 5—2-propanol and d-limonene, which is a mixture of an alcohol used in disinfection and a terpene that may be associated with cleaning products, fragrances or citrus fruits. All the chemicals listed in the factors above were positively correlated with the factor. Specific sources could not be associated with each group of chemicals within a factor; these factors most likely represent a combination of tasks, occupations and chemical groups contained in products (see online supplementary appendix table S3).

The factor loadings are subsequently linked to the occupations as mean factor loadings in figure 3A. This part of the figure may be used to relate the factor loadings, which are indicative of analyte influence, to the occupations that were measured to identify trends in exposures among specific occupations. Factor 1 (ie, solvent use in clinical laboratory procedures and floor stripping tasks) is positively correlated with CLT and FSW but negatively correlated with MEP, RN and DLT. Factor 2 is positively correlated with NA and MEP but negatively correlated with CLT. Factor 3 is positively correlated with NA, LPN and RN, which may be related to ethanol-based hand sanitation practices due to frequent patient contact, but negatively correlated with MEP, DA, CLT and DLT who may not use hand sanitation as frequently as nurses. Factor 4 is positively correlated with LPN and RT, who perform tasks such as hand and patient cleaning; factor 4 is negatively correlated with DA and DLT. Benzene is a major constituent of tobacco smoke and its association with factor 4 may be due to emission sources such as smoking, gasoline, or contaminant in solvents. It is worth noting that samplers were removed when employees went to smoke, but residual chemicals from the smoke may have remained on the employee. Factor 5 is positively correlated with LPN, DA and HK, who perform tasks such as general surface cleaning, but negatively correlated with RT, PT and CLT.

The association between sampler types was assessed using matched mobile area and personal samples representing 100 workers and 143 measurements, for whom both measurement types were available. Overall, there was a strong correlation between mobile area and personal measurements (r=0.88), which varied considerably by analyte (r=0.23 for α-pinene to r=0.64 for d-limonene). The correlations between sampler types for each analyte varied by occupation, but this relationship could not be fully evaluated due to the paucity of data for the combination of analyte and occupation. The mixed model results showed that all the fixed effects (mobile area sampler, occupation and analyte) as well as the interaction term between analyte and occupation were significant and explained a large fraction of the total variance (adjusted r^2 0.87) in predicting personal levels from mobile area measurements.

DISCUSSION

The personal VOC exposures varied considerably among occupations in terms of types and levels of exposure to specific VOCs. Exposure levels were higher for some VOCs such as ethanol, and lower with multiple measurements below the LOD for VOCs such as methyl methacrylates. Comparable exposure data were reported in a study of VOC exposures in six locations at a hospital in France[35] where the highest mean exposure levels were for ethanol (928 μg/m^3) and isopropanol (48 μg/m^3). They measured the highest alcohol concentrations in postanaesthesia care, nursing care and the hospital room. For their study, mean exposures to benzene, toluene, ethylbenzene, xylenes (BTEX) and chloroform were in the range of 1–10 μg/m^3, while to limonene they were in the range of tens of μg/m^3. These results are consistent with the findings from our study, albeit at slightly lower mean concentrations.

In the present study, while personal exposure estimates were well below occupational exposure limits,[36-38] a more appropriate comparison for the healthcare workforce may be indoor air quality guidelines. Guidelines have been proposed by the WHO and several

governments including the state of California (USA), Japan, Germany and Hong Kong and summarised in a report funded by the National Research Council of Canada.[39] As an example, Japan has the most conservative guideline for toluene (260 μg/m^3) based on long-term exposure. While the highest mean personal exposure from CLT (GM 162 μg/m^3) did not exceed the Japanese guideline; two histology technicians, who have been classified here as CLT, did have time-weighted average measurements (1430 and 787 μg/m^3) well above this guideline. A further discussion on the comparison of exposure estimates to indoor air guidelines is presented in the online supplementary appendix. Halogenated compounds other than chloroform and methylene chloride were also present (see online supplementary appendix table S2) and should be investigated further because they are lung irritants and important by-products of disinfection product use.

Epidemiological studies have reported increased risk of WRA among the nursing occupation, medical instruments disinfection and general use of cleaning and disinfecting chemicals.[3540] In this study, exposures to TVOCMIX, ethanol and/or propanol were among the highest for some nursing occupations (ie, certified NA and LPN) and MEP (involved in instrument disinfection) who frequently use cleaning and disinfecting products. RN had moderate levels of exposure to TVOCs, ethanol and/or propanol, which suggests that exposure levels to VOCs may differ among nursing occupations most likely associated with their work tasks or product use. Quantitative exposure estimates permit more resolved differentiation of exposure within an occupational category and thereby reduce the opportunity for exposure misclassification and enable quantitative risk assessment. Further research conducted by the authors will use these quantitative exposure estimates for epidemiological studies.

To minimise this misclassification, exposure estimates by occupation (eg, as assessed by a JEM) can be modified with information obtained by questionnaire about tasks, products and tools used, as well as information about other exposures of interest not in the JEM or quantities not measured. For example, in this study, exposure to certain asthmagens present in the hospital environment such as formaldehyde (among pathologists), ortho-phthalaldehyde and ethylene oxide (among MEP), or ethanolamines (among FSW, etc) was not measured but could be assessed via a questionnaire. This approach of incorporating relevant worker-specific determinants data (eg, products or tools used) from a detailed occupational questionnaire into a JEM can refine exposure estimates in the cells of a JEM; the refined JEM may better characterise worker-specific exposure circumstances and account for the potentially large between-worker variation within the same job.[41-43]

As noted earlier, we sought volunteers to participate in the exposure assessment survey and the number of participants varied by occupation in part related to the number of workers in that occupation. For example, we monitored 39 HK and FSW (using mobile area samplers) but only eight CLT in part because there are fewer CLT in most hospitals than HK. The number of workers sampled per occupation was roughly proportional to their distribution in the hospitals sampled.

In a study of healthcare workers from multiple occupations and hospitals, differences in exposures by occupation could be influenced by a number of factors, including hospital-

specific differences in chemical use, occupational duties (eg, frequency and duration of tasks) and type of institution. Owing to these differences in occupational exposures, exposure estimates cannot be generalised to other settings without taking into consideration the tasks performed by the occupation and the products used by facilities. Another limitation of the current study was the assessment of time-weighted average VOC measurements for full-shift exposure assessment instead of task-based or shorter term exposure characterisation. Peak exposures may be important for asthma outcomes, and full-shift measurements can dilute high intermittent exposures that occur during the shift. However, short-term sampling for specific analytes may be problematic due to analyte loading on traditional sorbent-based media and associated detection limits. Evacuated canister sampling can overcome this issue by adjusting the flow rate to collect the same volume of sample over a much shorter period. This approach will be investigated in the future for task-based sampling strategies. TVOC measurements were collected using real-time PID monitors to capture peak exposures during tasks; analysis of these data using time series modelling to associate specific events with exposures is ongoing. These differences in exposures will be explored in future work by modelling measured exposures and introducing covariates based on contextual information collected during exposure monitoring, including tasks performed, products and tools used and control measures present. The insight gained from these models will permit moving beyond the simple JEM to a more specific task exposure matrix or a model-based exposure estimate that takes into consideration the contextual elements that are associated with differences in exposures within and between occupations.

Exposures were modelled using PCA to reduce the number of variables and provide orthogonal input variables for other modelling techniques. Factor Analysis was not used here as the researchers did not want to influence or hypothesise a latent factor structure. The factor groupings from the PCA are merely chemical measurements that trended together based on statistical techniques and may not reflect real-world groupings (ie, a latent structure) such as chemical groupings by emission source (eg, BTEX from gasoline). Definitive associations among factors and occupations are not observed, indicating that other contributors may be driving the groupings. These possible contributors may include frequency and duration of products used and tasks performed by workers or by others in their vicinity (eg, floor cleaning by a HK affecting exposures to nurses). These statistical groupings may still be used for further modelling efforts. They may also be more appropriate than direct exposure measurement input as the factors are statistically unrelated and do not artificially affect modelling results due to potentially correlated chemical measurements. An example shown here was associating the factor loadings back with the occupations to investigate the relationship between factors and occupation. Since factor loadings varied by occupation, they may be useful as a predictor variable in epidemiological models, especially if the factors can be associated with a chemical identity such as aromatics for factor 1 or another latent structure like occupational tasks such as the use of solvents during laboratory procedures. Other investigators in the USA used data from the 1999–2000 National Health and Nutrition Examination Survey to investigate the association between asthma in adults and occupational exposures to VOCs summarised using PCA analysis.[20] They reported significantly higher ORs for physician-diagnosed asthma among workers exposed to aromatic compounds, which was one of two factors from their PCA.[20]

Occupational exposures to chlorinated hydrocarbons, the second PCA factor in their analysis, were significantly associated with attacks of wheeze among those without physician-diagnosed asthma. PCA is commonly conducted on VOC data to reduce the dimensionality of the data, and factor loadings or scores are often used as covariates in epidemiological studies when modelling health outcomes.[19]

Area measurements are often available, and are used to estimate or represent personal exposures because of the relative ease of collecting area samples in many work environments. However, area samples should be used with caution because the proximity of an area sample relative to the source and receptor may result in overestimation or underestimation of personal exposures.[44] In this study, we minimised such errors by using a mobile area sampling strategy to make the measurements more representative of personal exposures (as personal canister samplers were not available at the start of the study). While the overall association between mobile area and personal samples was good, the associations between the sampler types were mostly moderate to low for specific analytes. The discrepancy in mobile area and personal samples is most likely related to the mobility of the occupations, the placement of the mobile area sampler and the relative proximity of the two sample types to the source. For example, some occupations are relatively stationary such as MEP or PT, while others are relatively mobile such as HK and nurses. In addition, multiple circumstances arose where the area canister could not be located close to the worker such as when attending to a patient in a room or during surgery. Given the moderate correlations for specific substances, personal measurements may be estimated from mobile area measurements by taking into consideration the occupation and the analyte.

CONCLUSION

This study characterised exposures to 14 VOCs among 14 occupations in healthcare settings using a well-characterised evacuated canister sampling and analysis technique for assessing a mixed concentration scenario, where low-level VOCs were present in a high-level VOC background. A significant benefit of the evacuated canister sampling technique for healthcare settings was its ability to provide specific chemical information for a broad class of compounds as well as a measure of TVOC that may be important in evaluating the association of these chemicals with WRA. Exposures measured among these occupations track with health outcomes in terms of the prevalence of respiratory symptoms and/or asthma reported in such occupations as nursing and MEP. Quantitative estimates of occupational exposure to VOCs in healthcare settings generated here are needed by industrial hygienists for identifying high-exposure occupations and by epidemiologists to generate exposure metrics for inclusion in models of health outcomes among healthcare workers. These quantitative exposure estimates can augment current methods of questionnaire-based and selfreported exposures.[28]

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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What this paper adds

- US healthcare workers have a disproportionate amount of asthma. Available evidence suggests that exposure to chemicals in cleaning and disinfecting products may contribute to work-related asthma. Accurate characterisation of exposure to volatile organic compounds (VOCs) is needed.
- Results of air monitoring demonstrate that healthcare workers were exposed to a range of chemicals at varying concentrations. These exposures were most likely influenced by the tasks performed and products used during usual work duties.
- Quantitative estimates of occupational exposure to VOCs in healthcare settings generated here are needed by industrial hygienists for identifying high-exposure occupations and by epidemiologists to generate exposure metrics for inclusion in models of health outcomes among healthcare workers. These quantitative exposure estimates can augment current methods of questionnaire-based and self-reported exposures.

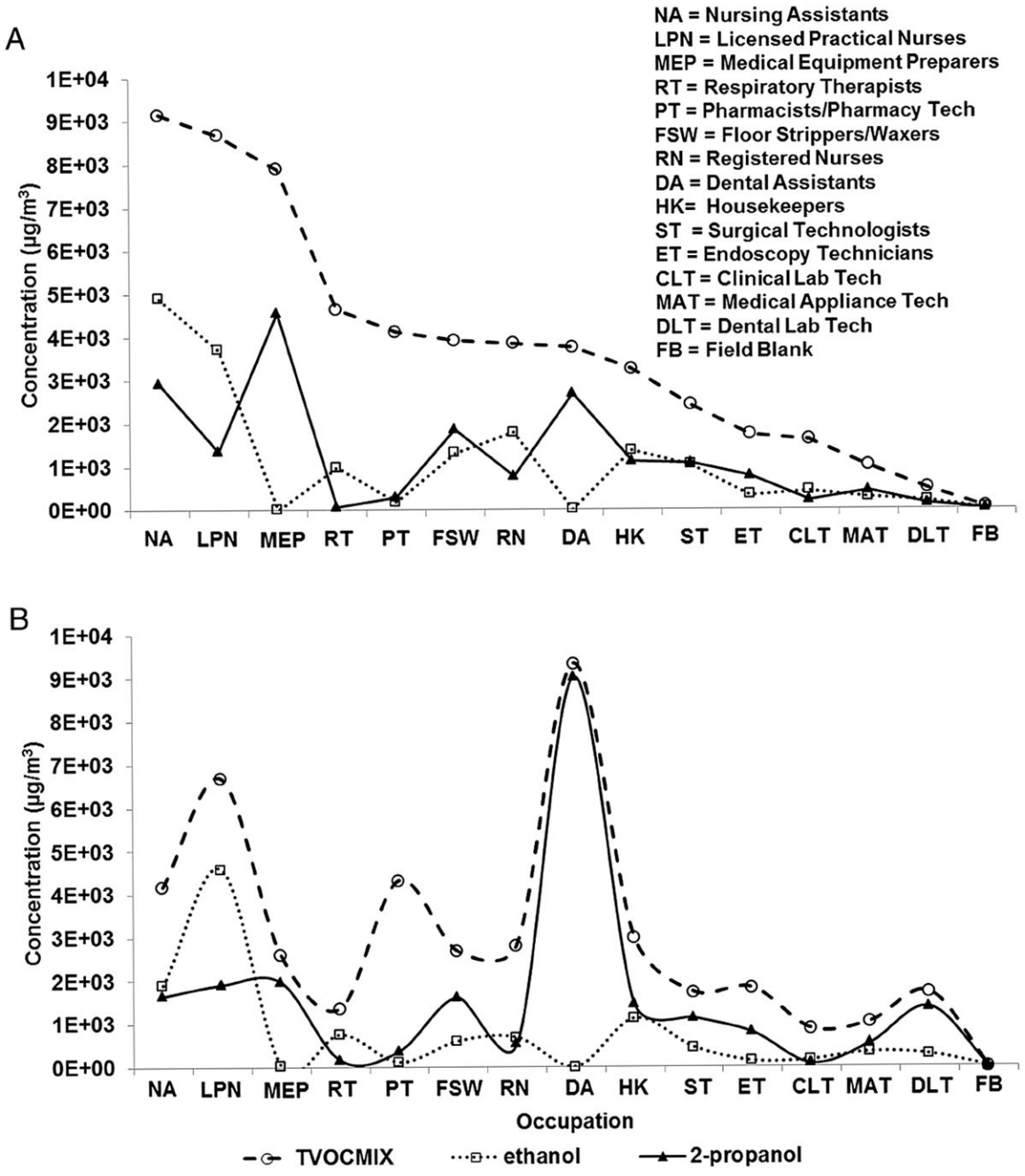

Figure 1.

Geometric mean exposure concentrations for (A) personal and (B) mobile area sampling for TVOCMIX, ethanol and 2-propanol by occupation.

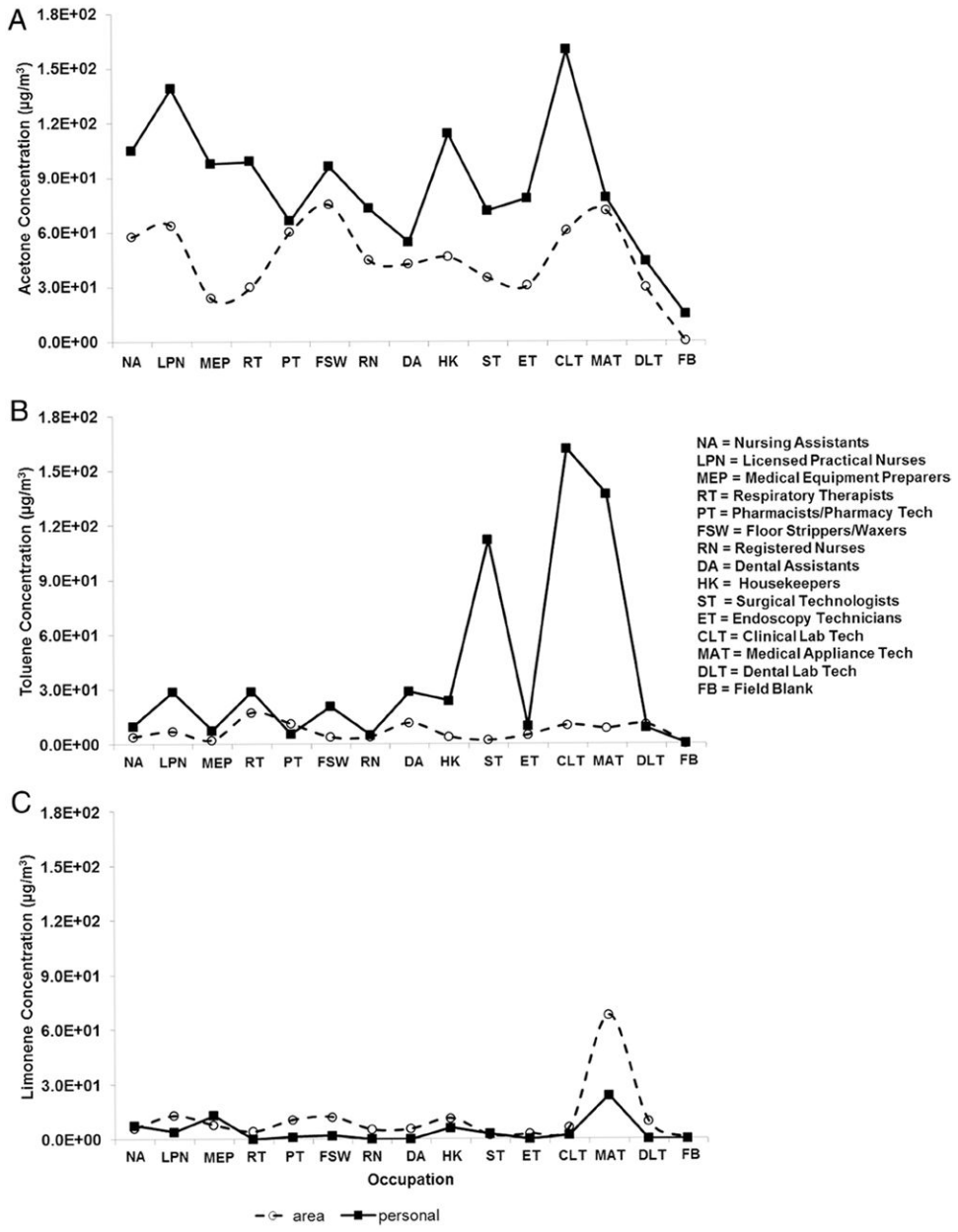

Figure 2.

Mobile area and personal sample concentrations by occupation for (A) acetone, (B) toluene and (C) limonene.

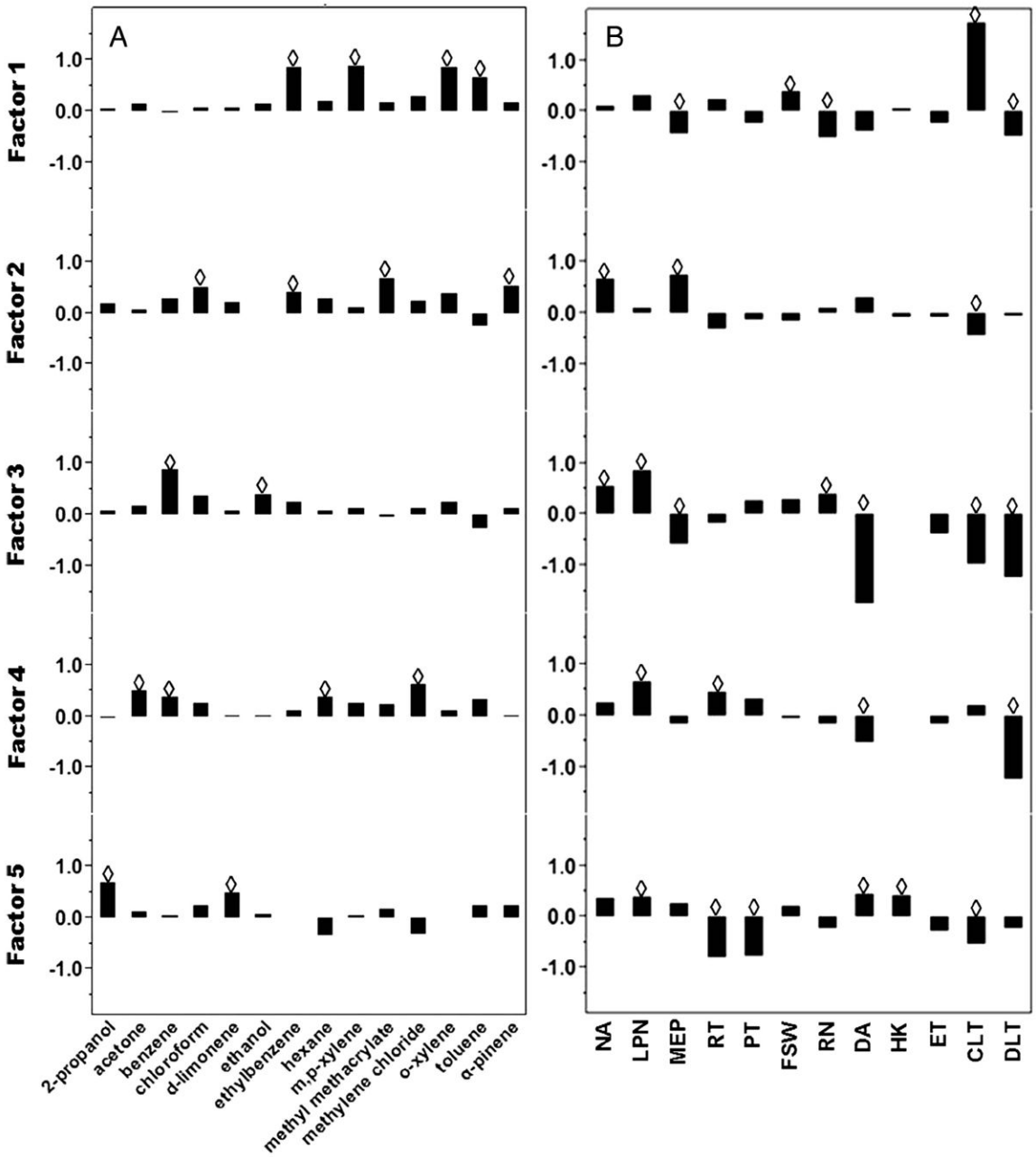

Figure 3.

Factor loadings by analyte (A) and occupation (B) based on personal samples. CLT, clinical laboratory technicians; DA, dental assistants; DLT, dental laboratory technicians; ET, endoscopy technicians; FSW, floor strippers/waxers; HK, housekeepers; LPN, licensed practical nurses; MEP, medical equipment preparers; NA, nursing assistants; PT, pharmacy technicians; RN, registered nurses; RT, respiratory therapists.

Table 1

Full-shift mobile area and personal volatile organic compound samples collected among occupations

Occupation	Hospitals	Mobile area samples	Personal samples	Mean (range) personal sampling time (h:min)
Clinical laboratory technicians	2	11 (8)	8 (6)	7:20 (6:37–8:10)
Dental assistants	3	11 (6)	4 (2)	6:50 (6:44–6:55)
Dental laboratory technicians	3	10 (5)	4 (2)	6:58 (6:20–7:55)
Endoscopy technicians	4	16 (11)	11 (7)	7:12 (5:35–8:04)
Floor strippers/waxers	4	13 (8)	13 (8)	6:44 (5:51–7:30)
Housekeepers	5	52 (31)	31 (20)	5:12 (3:07–7:47)
Licensed practical nurses	3	7 (6)	5 (4)	7:02 (6:20–8:03)
Medical appliance technicians	1	2 (1)	2 (1)	6:37 (6:13–7:02)
Medical equipment preparers	4	11 (7)	7 (5)	7:22 (6:06–8:12)
Nursing assistants	3	8 (6)	8 (6)	7:12 (5:38–8:10)
Pharmacists/pharmacy technicians	3	8 (6)	6 (5)	7:18 (6:14–7:50)
Registered nurses	4	44 (36)	34 (28)	7:07 (5:54–8:20)
Respiratory therapists	3	12 (8)	8 (4)	7:41 (6:43–7:52)
Surgical technologists	1	2 (2)	2 (2)	6:33 (6:01–7:05)
Total	5	207 (141)	143 (100)	

Values are displayed as number of samples with number of areas or workers in brackets. Full-shift measurements were mostly collected during the day and began at the start of the morning shift; floor strippers/waxers were sampled at night during their regular work schedule.